UDC 622.788:66.041.571

FLOW OF A GRANULATED MINERAL MATERIAL DURING FIRING IN A ROTATING FURNACE

A. N. Emel'yanov[1]

Translated from Steklo i Keramika, No. 2, pp. 31 – 33, February, 2005.

The behavior of a layer of material in a rotating furnace is considered in the context of mechanics of continuous media. Variations in the volume weight of the material layer are analyzed depending on the temperature in different furnace zones. It is found that elementary physicochemical processes in mineral granules generate surface forces in the layer of material that significantly influence the translational velocity of the granules along the furnace. It is established that the layer of granules during firing moves along the furnace length in waves (the Riemann waves). Different geometrical profiles of rotating furnaces are estimated.

As granulated mineral material is heated in the temperature interval corresponding to firing $T = T(x)$, the weight and volume of the granules before the swelling zone in a rotating furnace decreases gradually and consistently, which results in an insignificant increase in their volume weight. However, the volume weight of granules obtained from montmorillonite or montmorillonite-hydromica materials does not decrease, although the decrease in their weight and volume is significant. This is due to the specific structure of montmorillonite and hydromica crystals.

Figure 1 shows the variation of granule density ρ depending on x, where $x = x(T)$. This behavior of ρ variation persists up to the point M.

A further heating at temperatures corresponding to the temperatures in the swelling zone causes an intense growth in the volume of granules, whereas their weight remains virtually constant. A significant decrease in the volume weight of granules is observed. This dependence is indicated in Fig. 1 by the solid curve to the right of the point M.

In general the variation curve $\rho = \rho(x)$ (Fig. 1, solid curve) is the profile of ρ depending on the furnace length $x = x(T)$. The main specifies of this dependence is that it does not take into account the effect of the surface forces of inner interaction, which is a consequence of the physiochemical process of partial sintering (up to the point M) and swelling (to the right of the point M) that have a significant effect on the dynamics of material flows in the rotating furnace and, accordingly, on the product quality, furnace efficiency, and unit fuel consumption.

Figure 1 indicates by a dashed curve the bulk density profile ρ of the material that performs translational motion along the rotating furnace length x. The relation $x = x(T)$ is valid here. The bulk density grows with increasing x from the coordinate origin (charging of raw material into the furnace) to the point M'. On this segment the layer of material becomes compressed, since the volume of the granules decreases and, accordingly, $a'b' < ab$. To the right of the point M' (dashed curve denotes the swelling zone) the bulk density sharply decreases with increasing x. On this segment a significant rarefaction of material occurs, since $c'd' > cd$. The variation rate of ρ depends on bulk density and, therefore, the bulk density profile varies with time.

The bulk density profile of material moving in firing along the rotating furnace (Fig. 1) is the profile of density ρ depending on x in the final amplitude flat wave (Riemann wave) propagating to the right [1].

Within the wave segment up to the point M the bulk density of the material grows and the granules are brought closer, the segment $a'b' < ab$ becomes shorter and the wave profile on this segment becomes steeper. Within the wave segment to the right of the point M the bulk density of the material decreases under the propagating wave, the granules

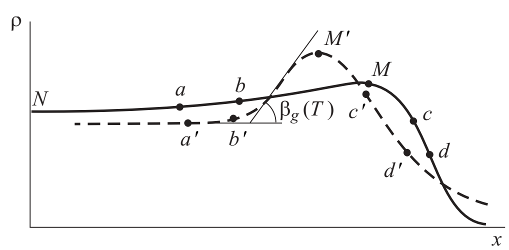

Fig. 1. Bulk density profile of material moving translationally along the rotating furnace in firing.

[1] Samara State Architecture-and-Construction Academy, Samara, Russia.

0361-7610/05/0102-0061

move apart, the distance between them grows ($c'd' > cd$), and the wave profile becomes smoother.

When the angle formed by the tangents to the point of intersection between the curve (dashed curve) of the new bulk density profile of the material in firing and the starting segment of the initial profile reaches the value of $\beta_g(T)$ that is equal to the angle of the dynamic slope of material at the swelling temperature, we observed a reversion of the wave of bulk density distribution depending on x and, accordingly, the firing temperature, since $x = x(T)$. On other words, the wave starts moving in the direction opposite to the direction of the material layer. In this way energy is dissipated and, according, the wave is extinguished. Therefore, the position of the point M on the profile curve ρ depending on x is unstable. The point M may shift to the left, up to the coordinate origin. With respect to the physical meaning of the firing process, such behavior of the point M agrees well with the actual swelling process in the rotating furnace.

It is generally known that the swelling zone (in Fig. 1 it is conventionally designated by the perpendicular drawn from the point M, i.e., from the zone of solid-phase chemical reactions) in a rotating furnace spontaneously shifts toward the cold (charging) end of the furnace, up to its flange.

The bulk density profile along the rotating furnace may vary with time. This indicates that the time of stay of granules and hot claydite in the rotating furnace may differ significantly from the firing duration, the first parameter being perceptibly longer. As a result, the product quality deteriorates, the furnace efficiency decreases, and the unit consumption of fuel in firing increases.

The regularities of the dynamics of material motion in a rotating furnace constitute the basis for designing up-to-date furnaces. It is convenient to analyze the dynamics of material motion in such furnace split by zones. The equation of dynamics of the translational motion of material in the swelling zone has the following form:

$$A = \rho_2 \frac{R_2^2}{2} (\Theta_2 - \sin\Theta_2)\, v_2^2 - \rho_1 \frac{R_1^2}{2} (\Theta_1 - \sin\Theta_1)\, v_1^2,$$

where A is the sum of the surface forces of inner interaction, kg · m/sec^2; ρ is the bulk density, kg/m^2; R is the furnace radius, m; Θ is the central angle of the segment taken by material, deg; v is the linear velocity of the translational motion of the material, m/sec; indexes 1 and 2 are the beginning (inlet) and the end (outlet) from the furnace zone, respectively.

It can be seen from the above equation that the furnace radius has a perceptible effect on the processes inside the furnace. With $R < 1$ mass transfer plays an important role in firing, with $R > 1$ the effect of mass transfer and primarily of diffusion flows decreases. Here we can note the increasing role of heat transfer. Rotating furnaces with $R = 1$ m have a transitional regime. If $A < 0$, there is mass exchange in the material flow (in a unit volume) not only with the external medium (with respect to the unit volume) but also inside this volume, i.e., spontaneous mixing of granules and swelling of hot granules. In this case ($A < 0$) mass transfer proceeds in the direction that is opposite to the direction of material under firing. This statement is corroborated by long-time industrial practice of rotating furnaces.

Having analyzed the results of studying the dynamics of the flow of material in a furnace, the optimum geometric profile of a rotating furnace has been developed, in which the drum and the cone are rigidly fixed to each other. This can serve as the basis for upgrading existing furnaces and designing new ones with a foundation base of 2.5 × 40 m. Let us perform a brief comparative analysis of the evolution of rotating furnaces compared to two-drum rotating furnaces designed in 1980 – 1990s (German trend, companies KHD Gumboldt Wedag AG and Blahton Kettenbauer GmbH KG).

Figure 2 presents the geometric profiles of rotating furnaces and the linear velocity diagrams of the translational motion of material flows in these furnaces.

Linear velocity diagrams of translational motion in furnaces are constructed provided that there is no granule outlet in the furnace and the translational motion is the result of the complex motion of the granules. Diagrams *1 – 3* are constructed for single-drum furnaces of the same length (40 m) and diagrams *4 – 6* are constructed for two-drum furnaces converted to a single strength, the lengths of the drums taken to be equal. This simplification was made for the comparative analysis of the furnace performance. For this reason the linear velocity diagrams are of approximate mature.

In single-drum furnaces the compression and rarefaction waves alternate consecutively. The rarefaction value is significantly larger than the compression value, and the height of the layer of material in the swelling zone is larger than in the preceding chemical-reaction zone. Therefore, in furnaces with a smooth profile and a variable section the wave is reversed and, accordingly, a backward flow of material arises, which lowers the furnace efficiency. In the drum-cone furnace, a rarefaction wave is developed in all zones, as the velocity of the flow of material constantly grows. In this type of furnace the formation of a back flow is excluded and, consequently, the swelling resource is more effectively utilized, the quality of finished product improves, and the furnace efficiency increases.

The linear velocity diagrams of the translational motion of material flow in two-drum furnaces differ significantly from the velocity diagrams in single-drum furnaces, as they have a higher output (200 – 300 thousand m^2 per year) and generally a higher rotational speed of the drums. The surface forces of inner interaction in material flows in these furnaces are significantly higher in these furnaces.

In two-drum furnaces the compression and rarefaction waves propagate separately. A compression wave arises in drums for thermal pretreatment and chemical reactions, whereas a rarefaction wave originates in firing (swelling) drums. When granules from the thermal pretreatment drum are poured into the firing drum, a velocity jump occurs, in-

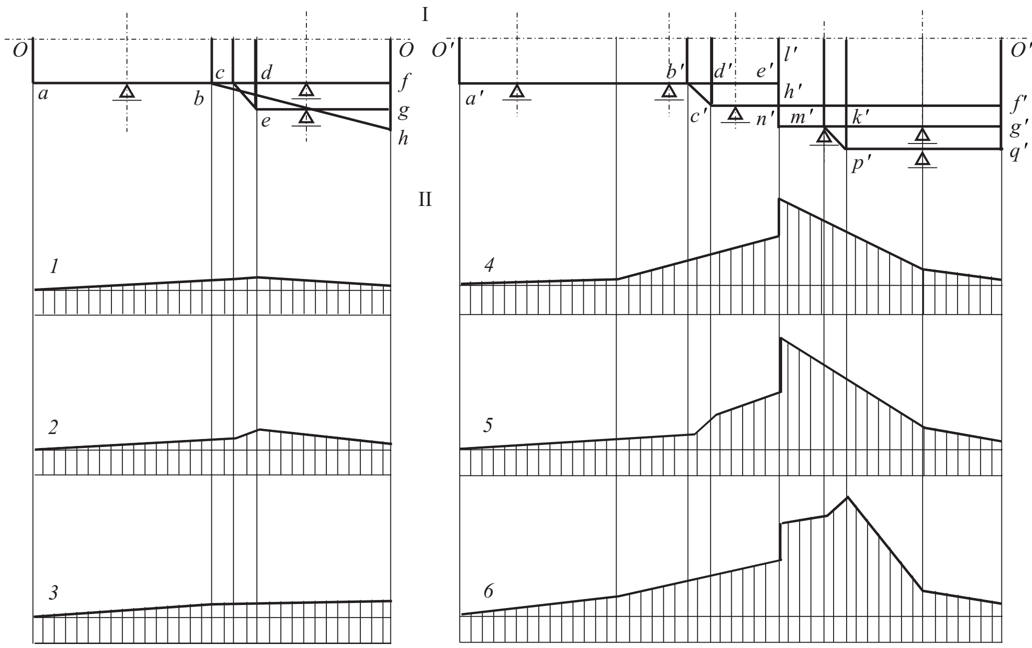

Fig. 2. Geometrical profiles (I) of rotating furnaces and linear velocity diagrams (II) of translational motion of material flows in these furnaces: *1* (*OabfO*)) single-drum with a smooth profile; *2* (*OacedO*)) variable section; *3* (*OabhO*)) drum-cone; *4* (*O' a' b' c' d' e' l' – l' n' g' O'*)) two-drum with smooth drums; *5* (*O' a' b' c' n' l' – l' n' g' O'*)) two-drum with variable-section first drum (German trend, KHD Gumboldt Wedag AG); *6* (*O' a' e' l' – l' n' m' p' q' O'*)) two-drum with variable-section second drum (German trend, Blahton Ketterbauer GmbhH KG); longitudinal axes of the furnaces are superposed and marked by horizontal lines *OO* and *O' O'* (furnaces with smooth drums developed in Italy, Finland, etc.).

tensifying the surface forces of inner interaction inside the firing drum and also intensifying the reverse flow formation. This flow gets stronger, as it has no obstacle from the side of the chemical reaction zone (which remains upwards, in the pretreatment drum). Expanding the end of the thermal pretreatment drum (diagram *5*) or of the firing drum (diagram *6*) does not eliminate the reverse flow, and, on the contrary, intensifies this flow, especially in the firing drum of the rotating furnace (diagram *5*).

In order to achieve maximum swelling, each granule of the intermediate material should receive the required amount of heat within the minimum possible time. This axiomatic condition requires an equality between the number of granules moving in different zones of the furnace, and this condition should be satisfied for the entire furnace length.

In view of the established specifics of motion of a flow of swelling batch granules (clay, construction powder, slag powder, or specially prepared glass), such as the nature of the wave, the instability of the direction and the value of the vector of surface forces of inner interaction, the jump in velocity, and the rarefaction, in designing new furnaces or upgrading existing ones it is necessary to base the design on the condition of the equality of granules over the furnace sections, which will make it possible to achieve the optimum effect not only with respect to swelling but also with regard to the volume of the rotating furnace.

Thus, the most cost-effective is the drum-cone type of furnace profile, in which the linear velocity of the material flow increases when passing the swelling zone.

REFERENCES

1. L. D. Landau and E. M. Lifshits, *Theoretical Physics, Vol. VI. Fluid Dynamics* [in Russian], Nauka, Moscow (1988).